ANALYSIS OF WDM AND WAVELENGTH ASSIGNMENT IN OPTICAL NETWORKS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

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Certificate

This is to certify that the work in the thesis entitled *Analysis Of WDM and Wavelength Assignment In Optical Networks* by Soumya Prakash Mahapatra is a record of an original research work carried out with my supervision and guidance in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Computer Science and Engineering. Neither this thesis nor any part of it has been submitted for any degree or academic award elsewhere.

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I would also like to thank the authors of all the books and websites which provided me with most of the data used by me in this project.

Last but not the least we would like to thank the God for showing the right way throughout the project.

TABLE OF CONTENTS

ACRONYMS

EDFA- Erbium Doped Fibre Amplifier

WDM - Wavelength Division Multiplexing

BER - Bit Error Rate

Q-Factor - Quality Factor

SMF – Single Mode Fibre

DCF – Dispersion Compensating Fibre

SOA – Semiconductor Optical amplifier

SNR – Signal to Noise Ratio

NF – Noise Figure

NRZ- Non Return-to-Zero

RZ - Return to Zero

RWA-Routing And Wavelength Assignment

1. ABSTRACT

The Project aims at designing and verification of different features of optical fibre communication system and then moves towards the architecture of WDM optical networks to meet the present day long distance, high data rate communication systems. For designing purpose the software OPTISystem 8.0has been used, which is a product of OPTIWave Systems. Various components available in the software are simulated for implementing the system. And for routing in WDM, C and MATLAB has been used for implementation of the algorithms.

Chapter 1

Optical Fiber Communication

1.1 Introduction:

Swift development in the information age continuously creates challenges in the communication sector. With the increase in data demands, 10 Gb/s networking has become grossly insufficient to meet all of the networking needs. This ensured the rapid adoption of 40 Gb/s networking standards for communication in the late 90s. 40 Gb/s IP router along with Wavelength Division Multiplexing (WDM) trials had also begun by the end of 2004. Although 40 Gb/s is well established in the current market but it is still insufficient for upcoming network applications. Currently, the industry is working on standardizing 100G technologies for much greater scalability and for more efficient optical data-rates. In order to match the ever increasing needs of high speed data communication, adoption of WDM has become imminent.

WDM Technology [1] is proposed as an alternative method for data carriage. With WDM one stand fiber can carry upto 128 channels now days [1]. WDM is independent of the format of data and data-rates. Routing and wavelength assignment (RWA) is the core of WDM systems [2]. RWA is a feature unique to WDM. In RWA, paths are selected from the source to destination and a wavelength is assigned to every path. Thus for an optical connection establishment, both the path selection (Routing) and the available wavelength allocation for the connections (Wavelength Assignment) must be handled. There are two pre-existing methods to solve the RWA problem. They are

- Consider routing and assignment as a single problem
- Consider routing and assignment as two separate problems.

In this thesis we have considered the ‘two as separate problem’.

1.2 Motivation and Objective:

1.2.1 Motivation:

WDM optical networks are the being widely adopted in data transmission because of features such as high speed, high capacity, low loss and better bandwidth. Therefore research in this field has been of much interest. Routing and wavelength assignment lies at the backbone of optical WDM networks. Today even more than 128 wavelengths can be assigned to a single channel for wavelength multiplexing. Several organizations like Texas Instruments, Broadcom, Ericsson etc. use WDM for achieving high speed in optical communication sector.

1.2.2 Objective:

The Objective of this thesis is to analyze the architecture of optical communication networks using different parameters like BER and Q-Factor. Then application layer algorithms for WDM networks are discussed for routing and wavelength assignment.

1.2 Optical Fiber Communication:

An optical fiber communication system entails four basic components:

- Receiver
- Transmitter
- Connecting optical fiber and
- Decision circuit.

The input signal is generated by a data-source from the transmitting end. Optical light signal is generated by laser at a fixed wavelength. The data source and the optical signal are input to the modulator and then the resulting signal propagates through the optical fiber. An optical sensor detects the incoming optical signal at receiver end. The signal received then passes through the demodulator to get the required output signal.

An optical fiber is a flexible thin filament which accepts electrical signal that is converted to optical signal. Then the optical signal being carried in the fiber is converted to electrical signal at the receiver end. The block diagram of an optical communication system is shown in figure 1.1.

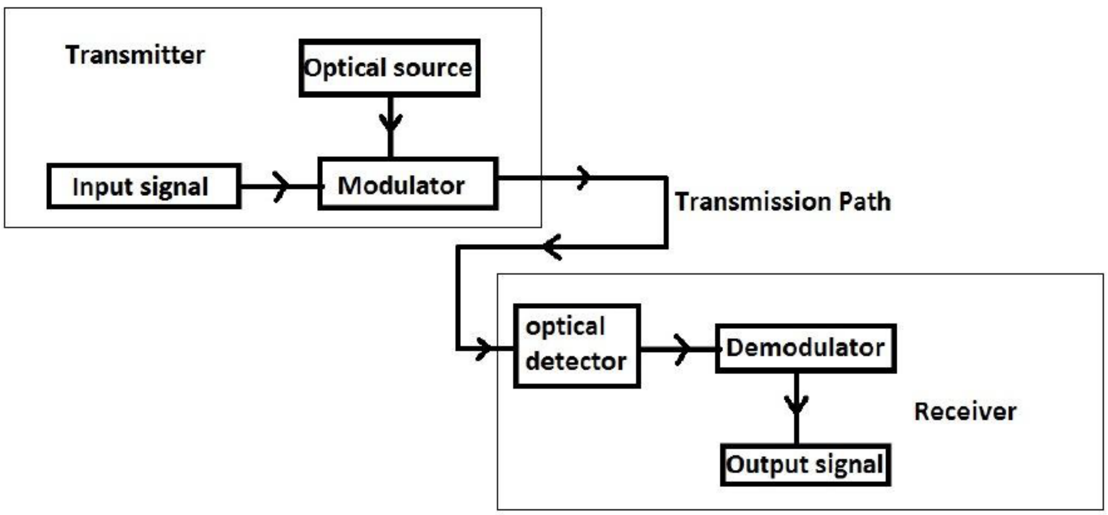


Figure 1.1 showing block diagram of optical communication.

The thesis is organized in to five sections or chapters. The first chapter gives an introduction of optical fiber communication, then second chapter describes the architecture of 10Gbps optical communication system and third chapter considers different features of WDM and its performance. Then last two chapters (fourth and fifth) addresses the application layer issues for routing and wavelength assignment.

Chapter 2

10 Gbps Optical Communication

2.1 10 Gbps Optical Networks-

Swift development in the information age continuously creates challenges in the communication sector. With increasing data-demands, 10 Gb/s networking has emerged to a new era. The earlier optical fiber links that were deployed around 1980s consisted of simple point to point connections [9]. The challenging issues were signal attenuation, noise, cross talk, spectral dispersion etc. So, an architecture of 10Gbps network is presented and performance of PIN photodiode is considered in this thesis.

2.2Literature Survey-BER performance analysis of PIN photodiode in 10Gbps fiber optical communication:

Components Used-

- 1.Psuedo Random Number Generator- It generates a random bit sequence according to different operation modes. The bit sequence is designed to approximate the characteristics of random data.
- 2.NRZ Coding- Generates pulse according to PRBS sequence.
- 3.Laser- Generates a continuous wave optical signal.

➢ 4.Optical Modulator- Using electro-optic effect, voltage is applied externally to vary the refractive indexes. Then intensity modulation takes place by applying voltage.

➢ 5.PIN Photo Diode- The optical signal obtained from fiber is filtered and converted to electrical signal.

The circuit diagram is shown in figure 2.1

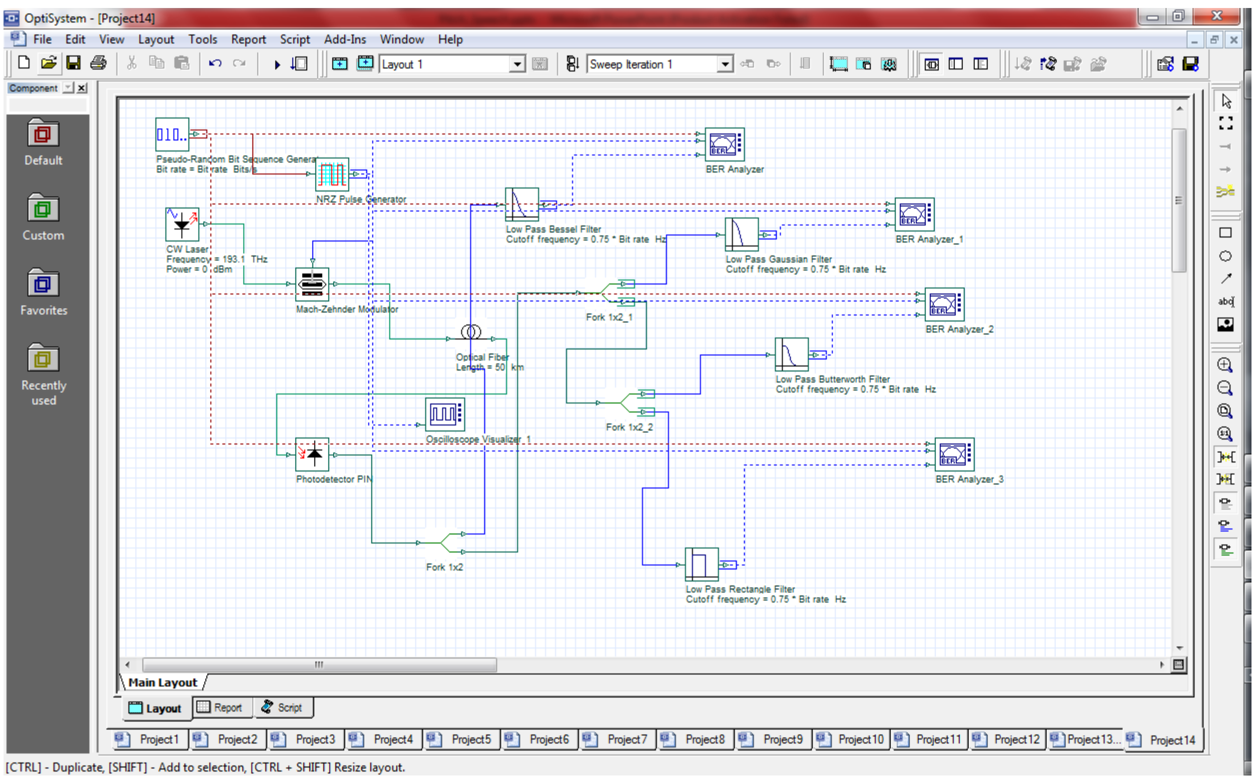


Figure 2.1 showing 10Gbps network

2.1 Performance Analysis- The performance of rectangular and Bessel filter has been compared in terms BER and Q-Factor.

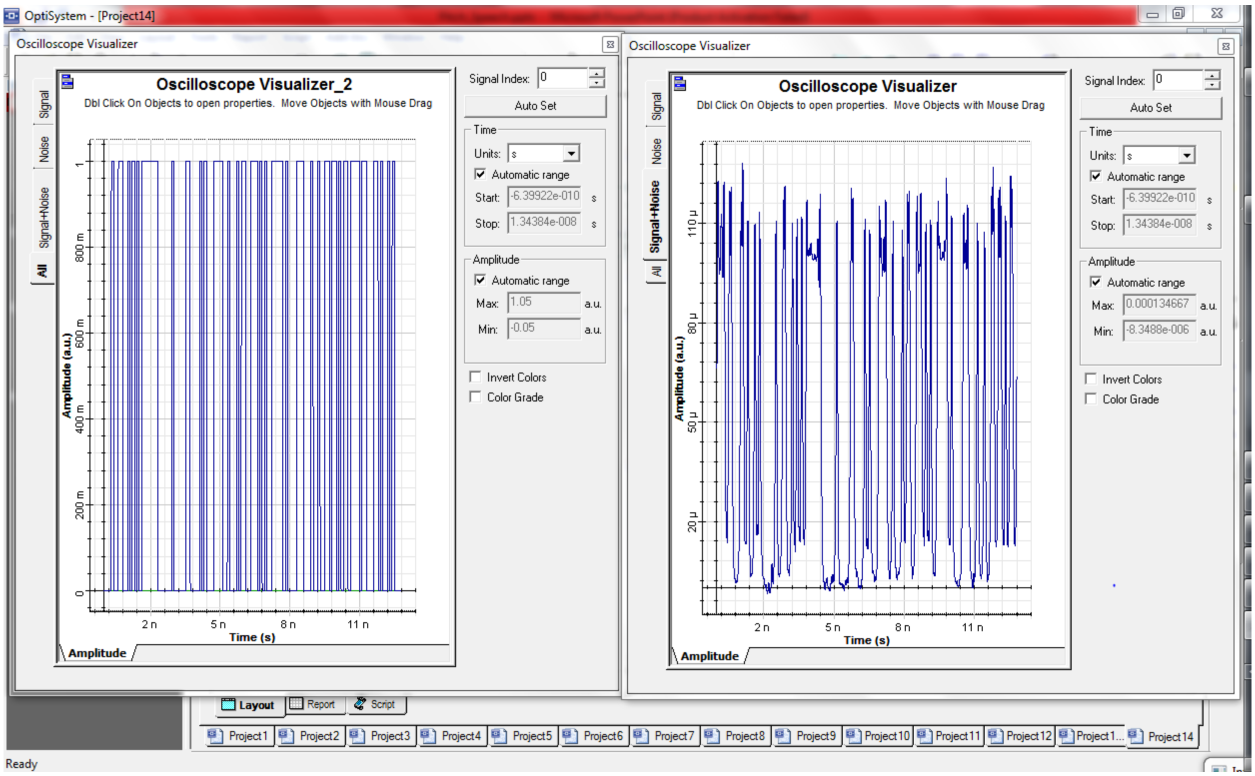


Figure 2.2 Input and output wave form

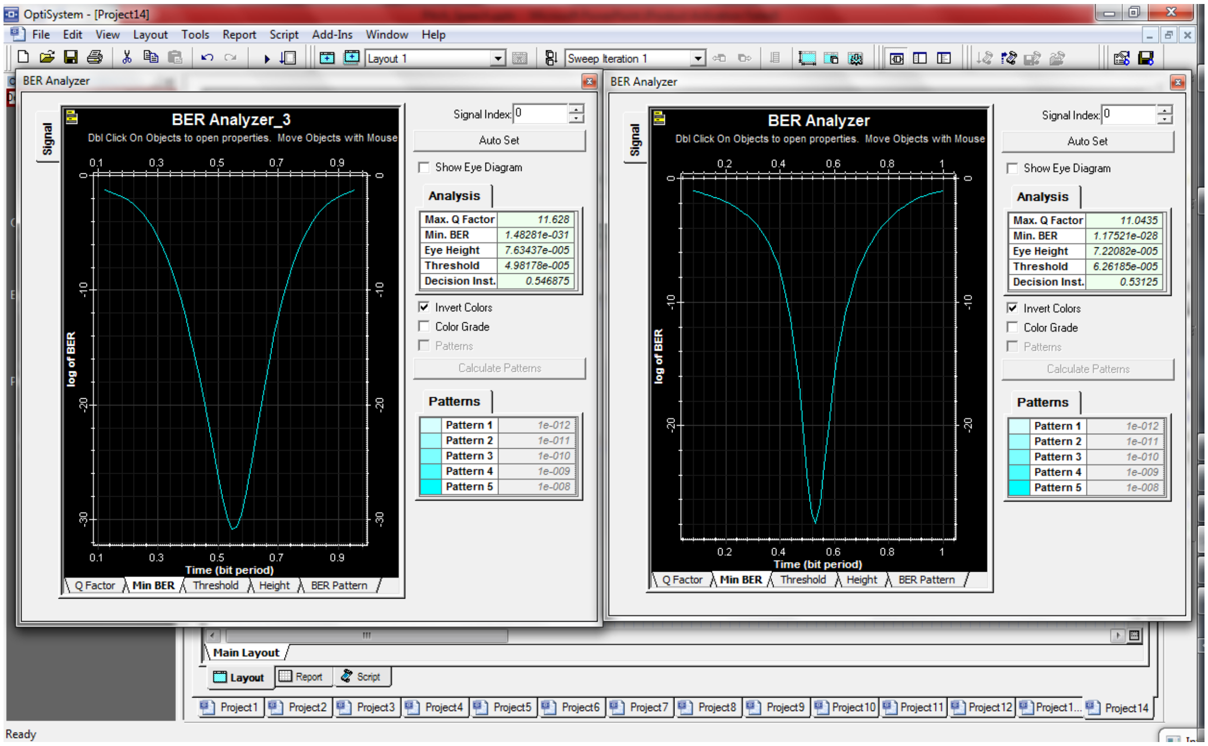


Figure 2.2 showing BER analyzer of rectangular and Bessel Filter (Left rectangular and right Bessel)

Output: In the above architecture, we have achieved maximum. Q-factor of 11.0435 and minimum.BER of 1.175e -028. But for achieving high speed we must go for WDM which can implement several 10 Gbps channels for 1 single mode fiber.

Chapter 3

Wavelength Division Multiplexing Architecture

3.1 Overview of WDM:

An operational feature of optical fiber is the spectral region of efficient transmission. For operation at full spectrum, spectral region includes O-band through L-band and it ranges about 1260 to 1675 nm [9]. Since the light sources used in the optical communication emit a narrow width of wavelength band less than 1 nm, many different optical channel segments can be used and this technology of combining a number of such independent information carrying wavelengths on to the same fiber is known as wavelength division multiplexing [9].

Earlier optical communications were based on link-to-link or point-to-point connections. The links contained a fiber and single laser was used at transmitting end. So, only a small slice of optical bandwidth was used and these small systems critically underutilize the large bandwidth. Hence WDM was introduced to maximize the bandwidth utilization in optical communication. So, in the next section we'll focus on the architecture of WDM systems.

3.2 WDM Architecture:

In any optical communication, our motto is to achieve low loss and high speed, better bandwidth, and high capacity. So, we need to tackle several issues in architectural design of WDM systems.

Several issues in WDM are-

1. Signal Attenuation
2. Presence Of Noise
3. Opto-electronic devices are costly
4. Blocking
5. Others

So, we have used the following components to challenge the above issues.

Components Used:

1. DCF(Double Clad Fiber For Dispersion Compensation)
2. SMF(Single Mode Fiber)
3. Psuedo Random Bit Generator
4. Bit Coder
5. Laser
6. Modulator
7. Multiplexer
8. PIN Photo Diode
9. Signal Processing Devices
10. Decision Circuit
11. Optical Amplifier

12.Demodulator

13.Decision Circuit

The architecture of WDM is shown in figure 3.1 and performance is analyzed in terms of BER,Q Factor etc. The architecture was simulated in OPTIWAVE 8.0.

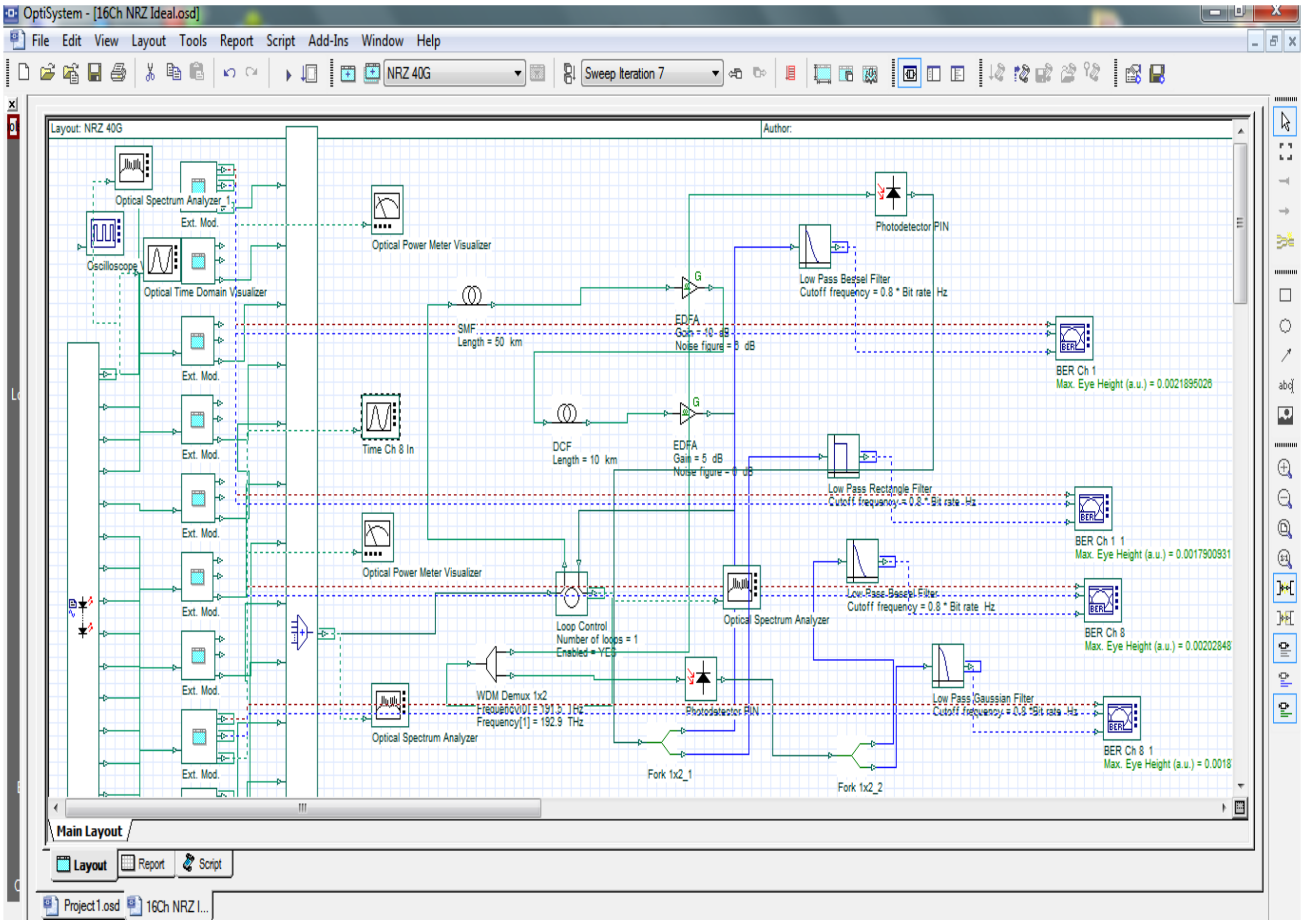


Figure 3.1 showing WDM architecture and performance analysis in BER analyzer

3.2 Performance:

We have shown the performance in terms of BER, Q-factor using different digital filters like Bessel Filter, Rectangular filter and Gaussian filter.

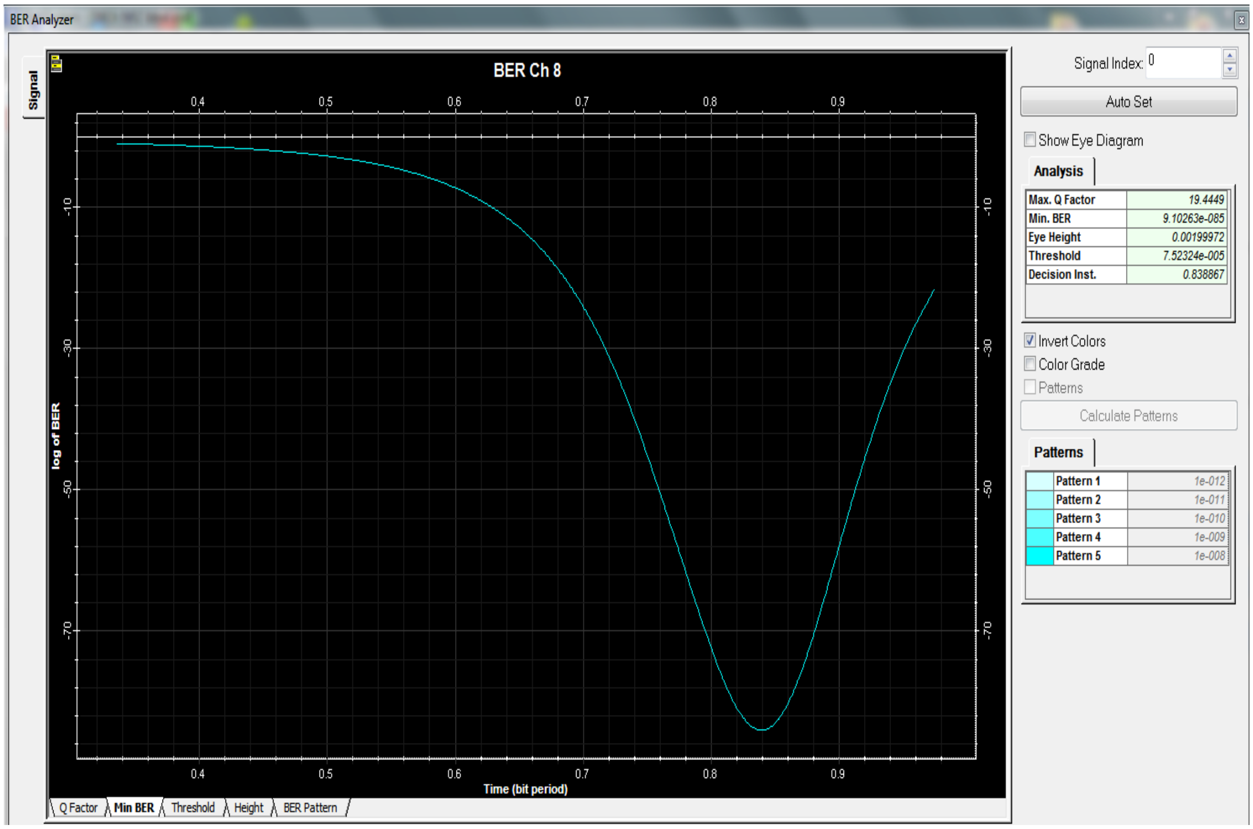


Figure 3.2 showing performance of Low-pass Bessel Filter

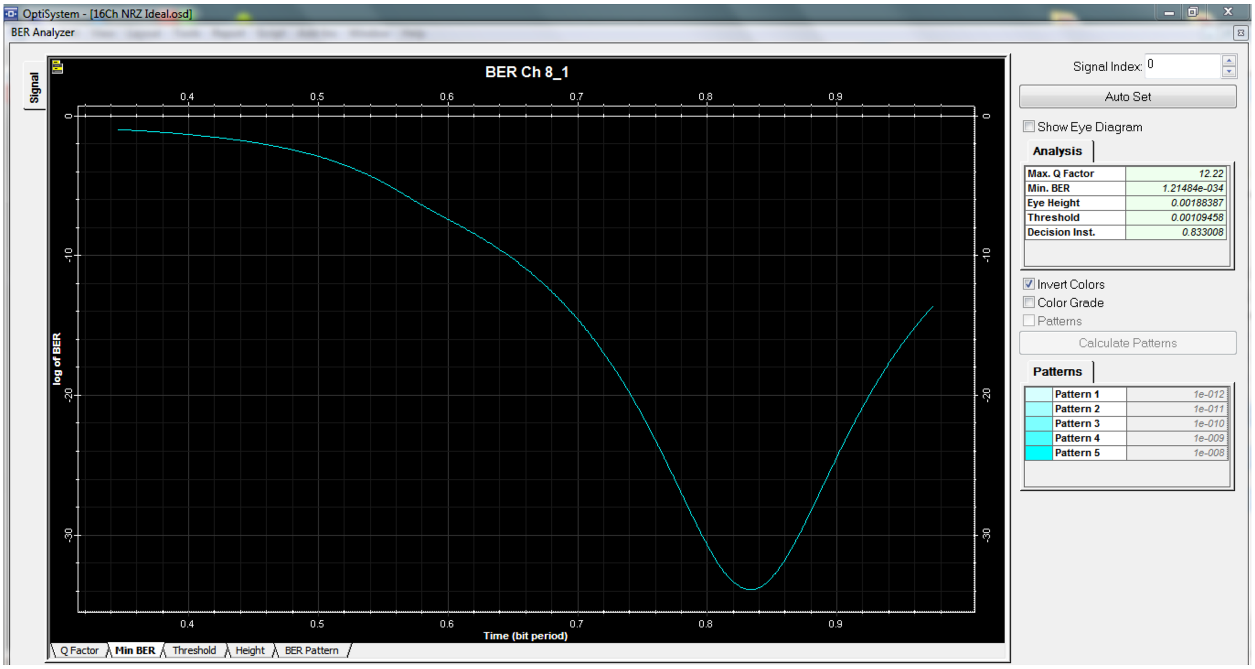


Figure 3.3 showing performance for Low-Pass Gaussian Filter

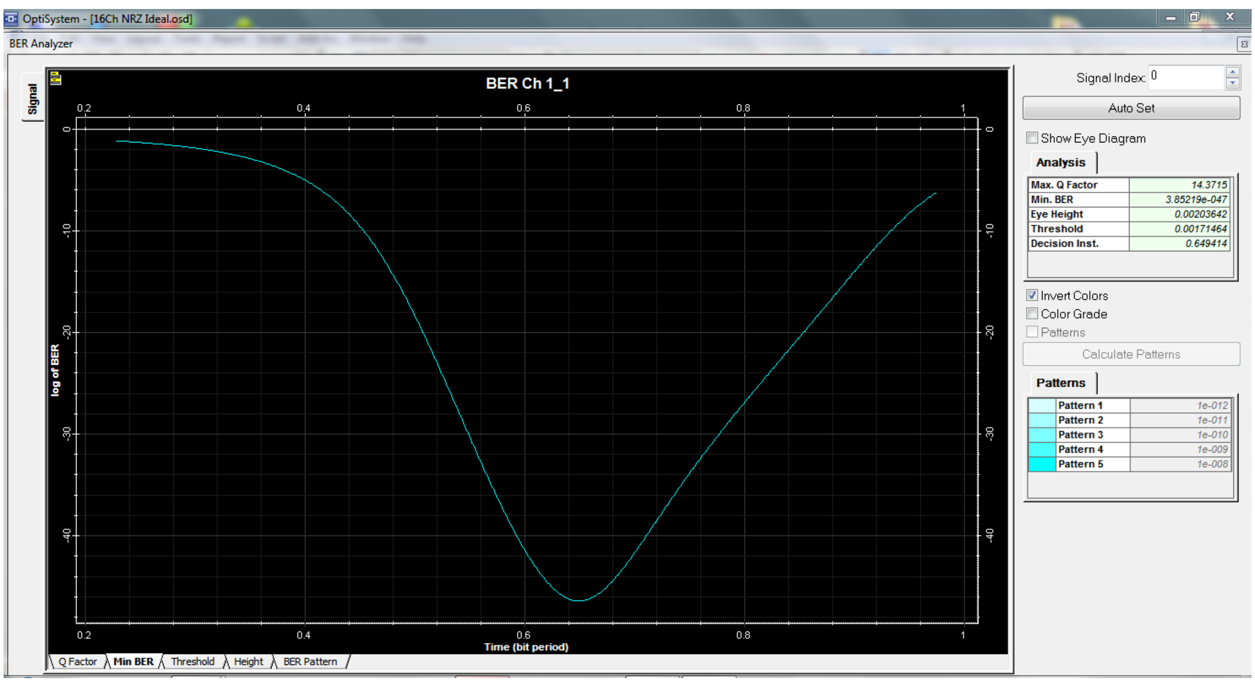


Figure 3.4 showing performance of Low-Pass Rectangular Filter

3.3 Results: Bessel filter performs comparatively better than others. Maximum Q-Factor in Bessel =19.45 and Minimum BER=9.01 e-085.

Chapter 4

Routing In WDM

4.1 Introduction (Routing in WDM):

One of the important characteristics of the optical fiber is its huge low-loss bandwidth of several tera-hertz. As a result of dispersive effects, only a small fraction is used for channel transmission. Wavelength Division Multiplexing (WDM) has become the choice for taking maximum advantage of fiber capacity. WDM technology [1] is proposed as an alternative method for carrying the data. With WDM, an optical fiber can put up about 128 channels now. Routing plays a vital role in wavelength division multiplexing. Several routing algorithms like fixed routing, fixed alternate routing, adaptive routing etc. have been proposed in the literature. But here we have considered fixed routing.

4.2 Routing Algorithms:

Performance of a network depends on blocking probability, path-length, interference-length, switch-size etc. and these parameters strictly depend on the choice of routing algorithm**.** Several algorithms proposed in the literature are**,**

Fixed Routing [3] The path for the source destination pair is calculated off-line using algorithms, say, Dijkstra algorithm.

Fixed alternate routing [3-4]: Instead of calculating one path for each pair, several alternate paths are calculated off-line in fixed alternate routing.

Adaptive routing [5]: the paths are calculated online, depending on the networks state which reflects the resource usage.

4.3 Proposed Algorithm:

The proposed algorithm is based on fixed routing considering 'Quality degradation threshold'. Quality degradation threshold is the dynamic parameter of a network which measures quality in terms of cost which is dynamic.

Algorithm-

Input: A graph with finite no of vertices and edges

Output: Path from source and destination.

- **Step A**: Initialize the path-length of all vertices to infinity and predecessor of all vertices to NIL. Make status of all vertices temporary.
- **Step B:** Make the path-length of source vertex equal to zero.

- **Step C:** Find the vertex with minimum value of path-length from temporary vertices and make it permanent and now this is our current vertex.

- **Step D:** Examine all temporary vertices adjacent to the current vertex. The value of path-length is recalculated and re-labeling is done if required.

  If s is source vertex and ‘current’ is the current vertex and v is temporary adjacent to ‘current’ **,**

  If pathLength(current) + weight(current,v) <pathlength(v)

  and Quality_Degradation Threshold>QD(current,v)

  then

  pathLength(v) = pathLength(current) + weight(current,v)

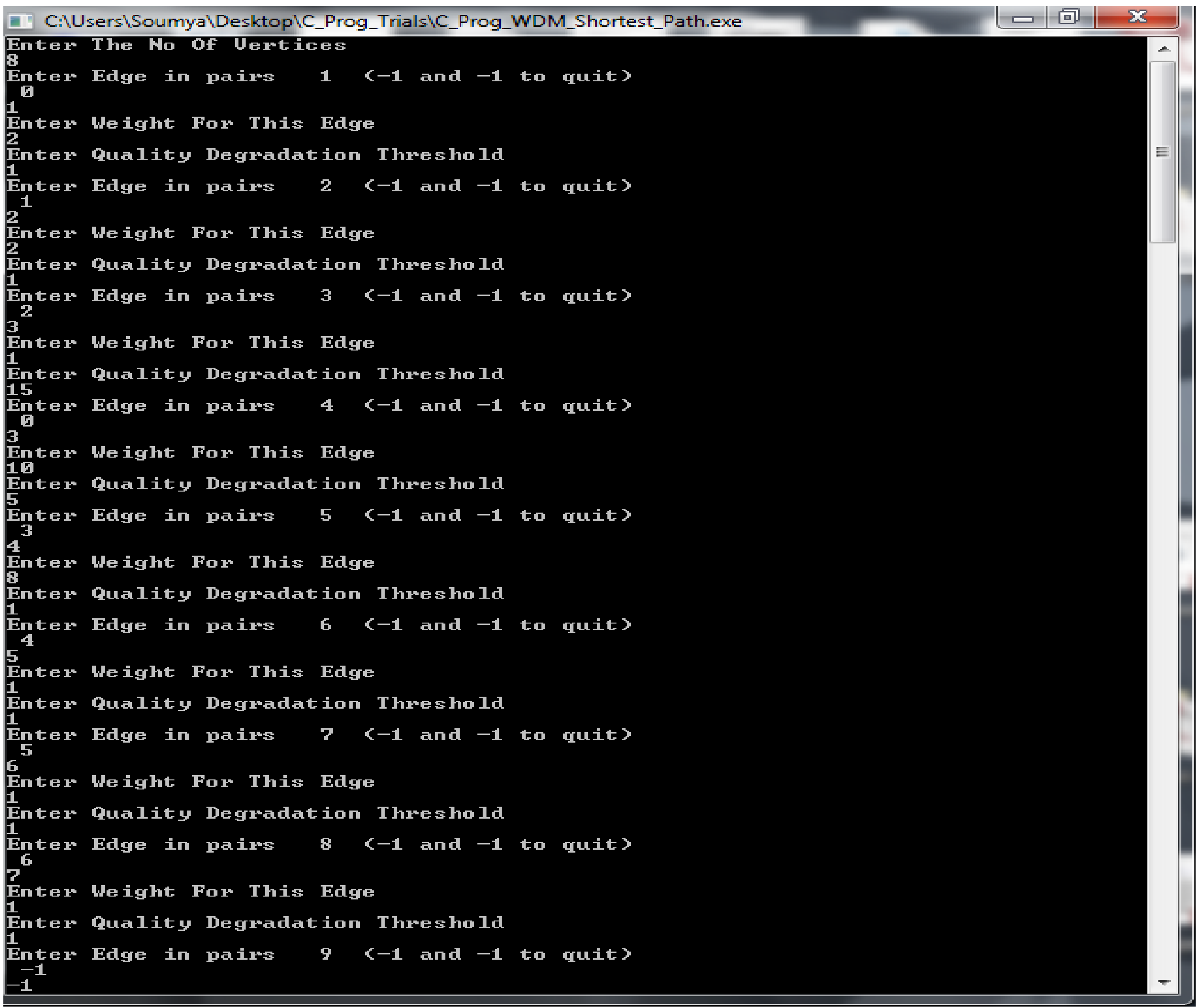
  else

  No re-labeling

- **Step E:** Repeat step C and D until there is no empty vertex left in the graph or all the temporary vertices left have path length infinity.

4.4 Result:

The algorithm is simulated using a specific network with 8 no of nodes, considering several quality-degradation-threshold values. No of channels used in the network=3, and simulation result is shown in figure 4.1. and the language used is C in gcc compiler.



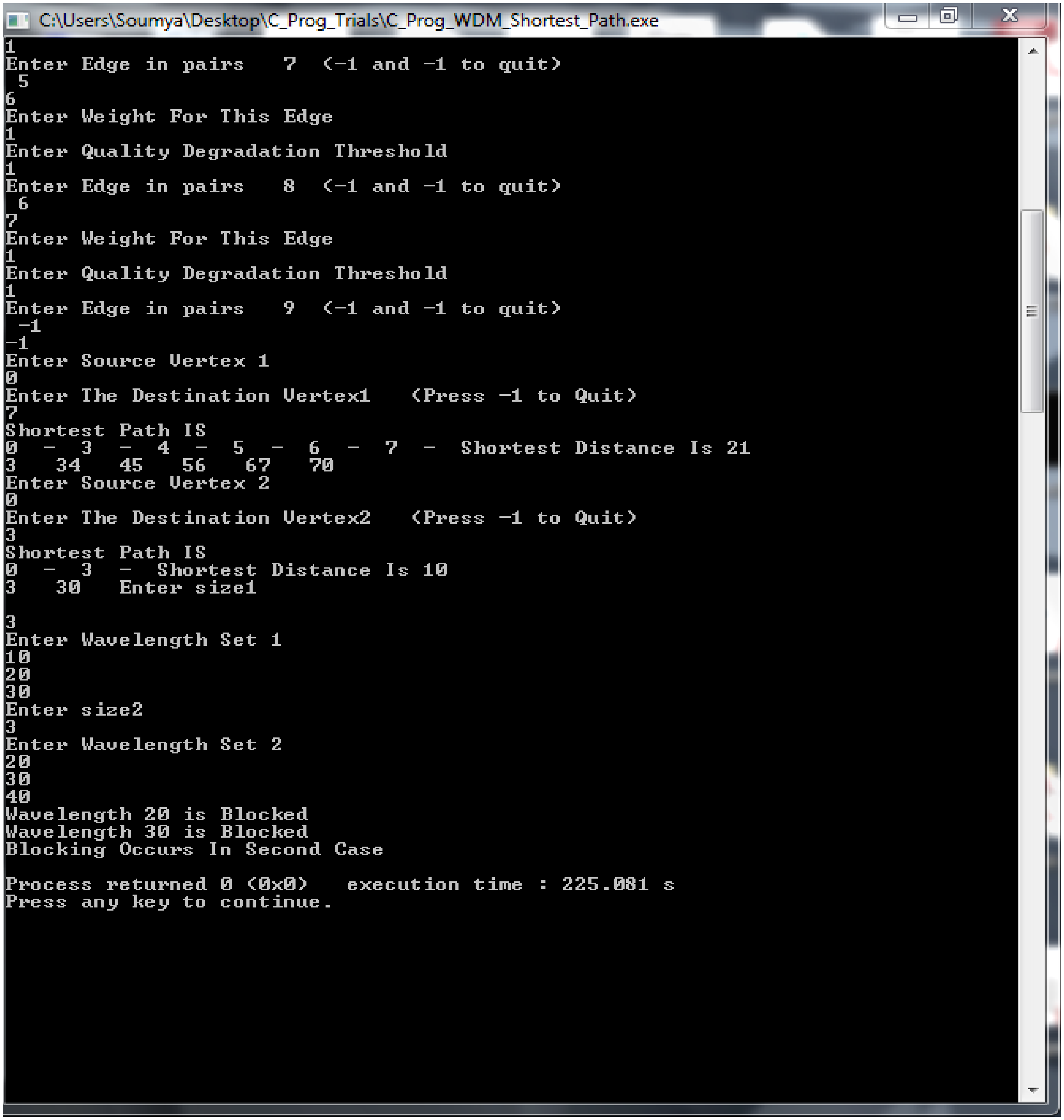


Figure 4.1 showing simulation of routing algorithm

Chapter 5

Wavelength Assignment

5.1 Wavelength Assignment In Optical Networks:

Sitting in the heart of WDM is the Routing and Wavelength Assignment (RWA) problem [2]. In RWA, light-path is established by proper selection of edges between source and destination nodes, and then wavelength is reserved for each links of the path. Since, we have considered the problems of routing and wavelength assignment as two separate solutions, the former part was discussed in previous chapter and in this chapter we are going to address the later one.

There are 2 constraints which must be dealt with for wavelength assignment-

1. **Wavelength Continuity Constraint:**

   A light path must use the same wavelength on all the links along the path from source to destination.

2. **Discrete Wavelength Constraint:**

   All light paths using the same link must be allowed distinct wavelengths.

Many wavelength assignment algorithms have been proposed in the literature. Some of them are:

1. **Random wavelength assignment [6]:** A wavelength is selected randomly from the available wavelengths.
2. **First-fit assignment [5]:** All the wavelengths are numbered. The wavelength with the lowest number is selected from the available wavelengths.

5.2Analytical Model Showing Performance Analysis:

IN AN all-optical network, from source to destination, the signal remains in optical domain. Our focus is on circuit-switched optical networks retaining wavelength-division multiplexing, in which path of signal depends on wavelength. The nodes in the network are connected in arbitrary mesh topology. We have considered both the case of wavelength converters and without converters.

Richard A. Barry [8] proposed a model for performance analysis of optical networks in which a comparison has been made the networks with wavelength converters and without converters with same value of blocking probability. An analytical model for performance analysis has been proposed, which is based on blocking-probability(Pb), hop length(H), no of channels(C), load and wavelength utilization(p). Figure 5.1 shows an H hop request and our analysis is based on that path from source to destination in that connection-request.

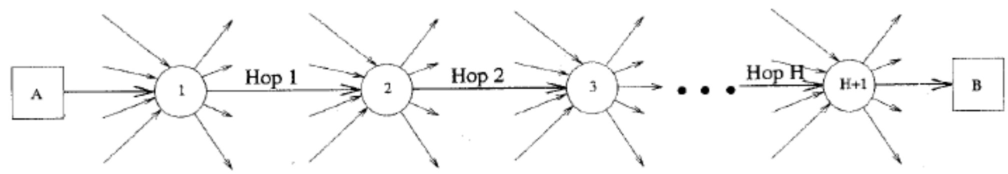


Figure 5.1 showing an H hop request.

Consider the request shown in figure 5.1, in which A is the source and B is destination. Let us define,

p= Probability that a wavelength is used in a hop (without converter)

q= Probability that a wavelength is used in a hop (with converter)

F=No of wavelength used

H=No of links between source and destination

Pb=Blocking probability (without converters)

Pb_C= Blocking probability (with converters)

G=Gain in utilization

Now we will analyze the performance of a network with wavelength converters in next section followed by the case with wavelength converters and gain.

5.3 Effect of path length on blocking probability:

Let p be the probability that a wavelength is used on a hop. Then pF is the no of wavelengths which has been used. So, p measures utilization of fiber along a particular path. Note that since pF is the expected number of busy wavelengths, p is a measure of the fiber utilization along this path. First, consider networks with wavelength converters. The probability Pb_C that the request between A and B is blocked is the probability that all the wavelengths have been used.

$$Pb\_C = 1-(1-qF)^{H}$$

So, utilization achieved for a given blocking probability is,

$$q = [\ 1- (1-pb\_C)^{1/H}]^{1/F}$$

$$\text{or} \qquad q \sim (Pb\_C/H)^{1/H} \quad \text{(For small Pb\_C/H)}$$

In figure 5.2 we have shown a plot for utilization q with F for different values of H, with blocking probability Pb_C=0.001.

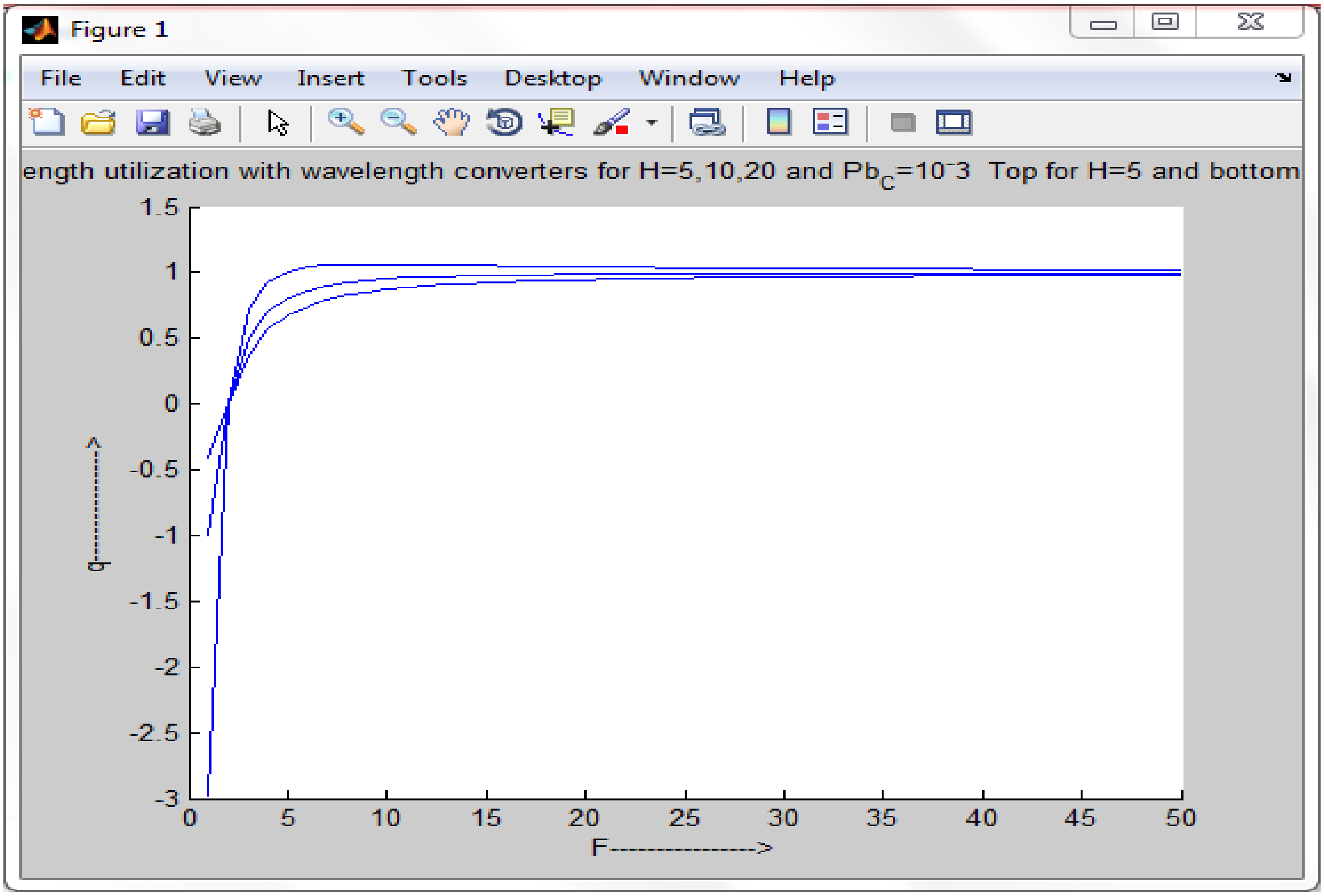


Figure 5.2 showing fiber utilization for Pb_C=0.001, for H=5,10 and 20

Now, let's consider the case without -wavelength converters. In this case Pb is the probability that each wavelength is used in one of H hops for at least one time.

$$Pb = [1-(1-p)^H]^F$$

Or $$p = [1-(1-Pb^{1/F})^{1/H}]$$

Or $$p \sim (-1/H)\ \ln (1-Pb^{1/F})\ \ \text{(For large H)}$$

The result is shown in figure 5.3 with Pb=0.001, H=5, 10, 20

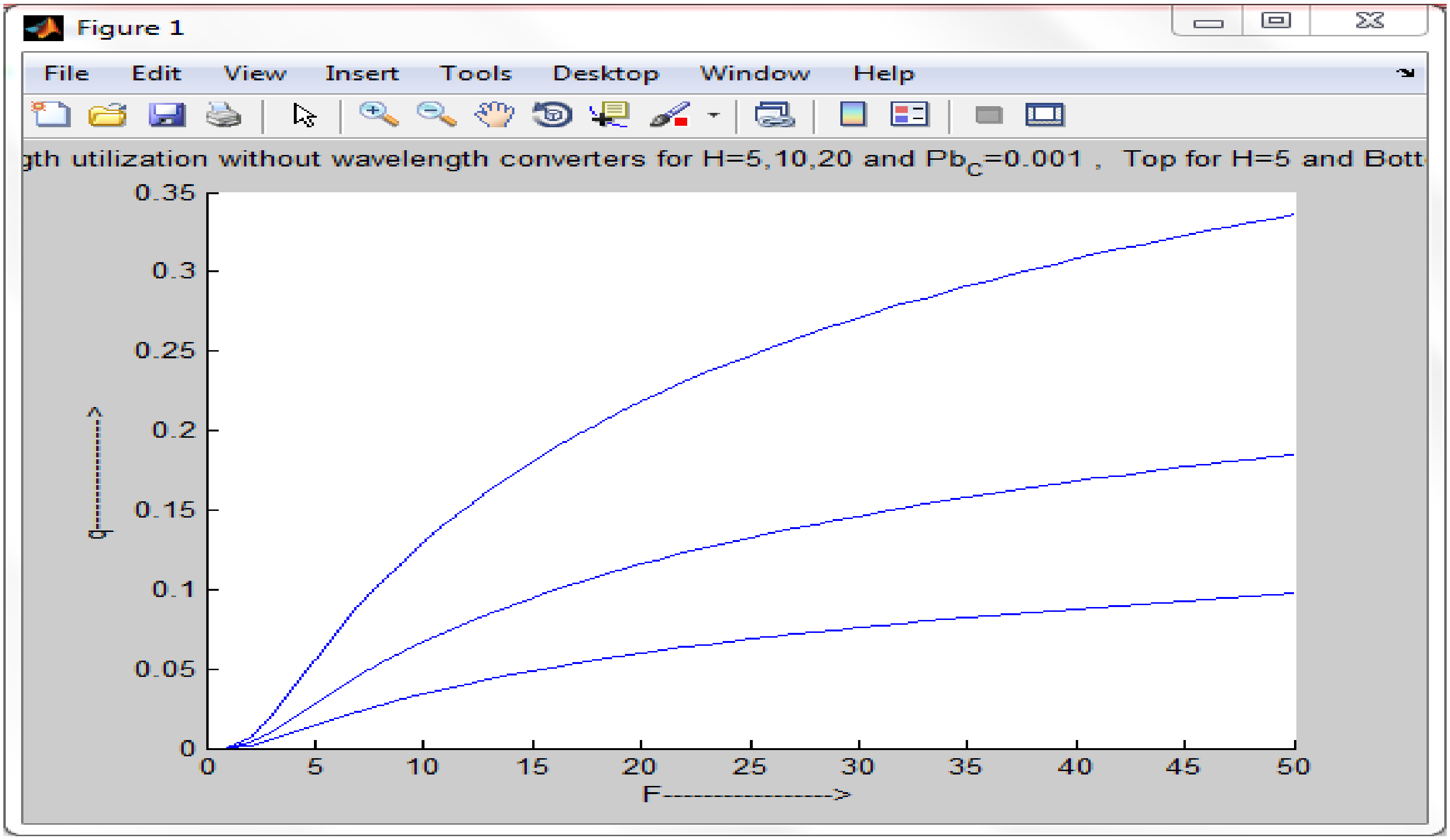


Figure 5.3 showing utilization for Pb=0.001, H=5, 10, 20

Now, we will consider the gain in utilization. Gain can be defined as the ratio of utilization in case of with-converter to with converter.

$$\text{Gain(G)} = \frac{1-\left((1-\text{Pb})^{\frac{1}{\text{F}}}\right)]^{1}/\text{F}}{1-\left(1-\text{Pb}^{\frac{1}{\text{F}}}\right)^{1}/\text{H}}$$

Plot for gain(G) is shown in figure 5.4 for Pb=0.001, with H=5, 10, 20

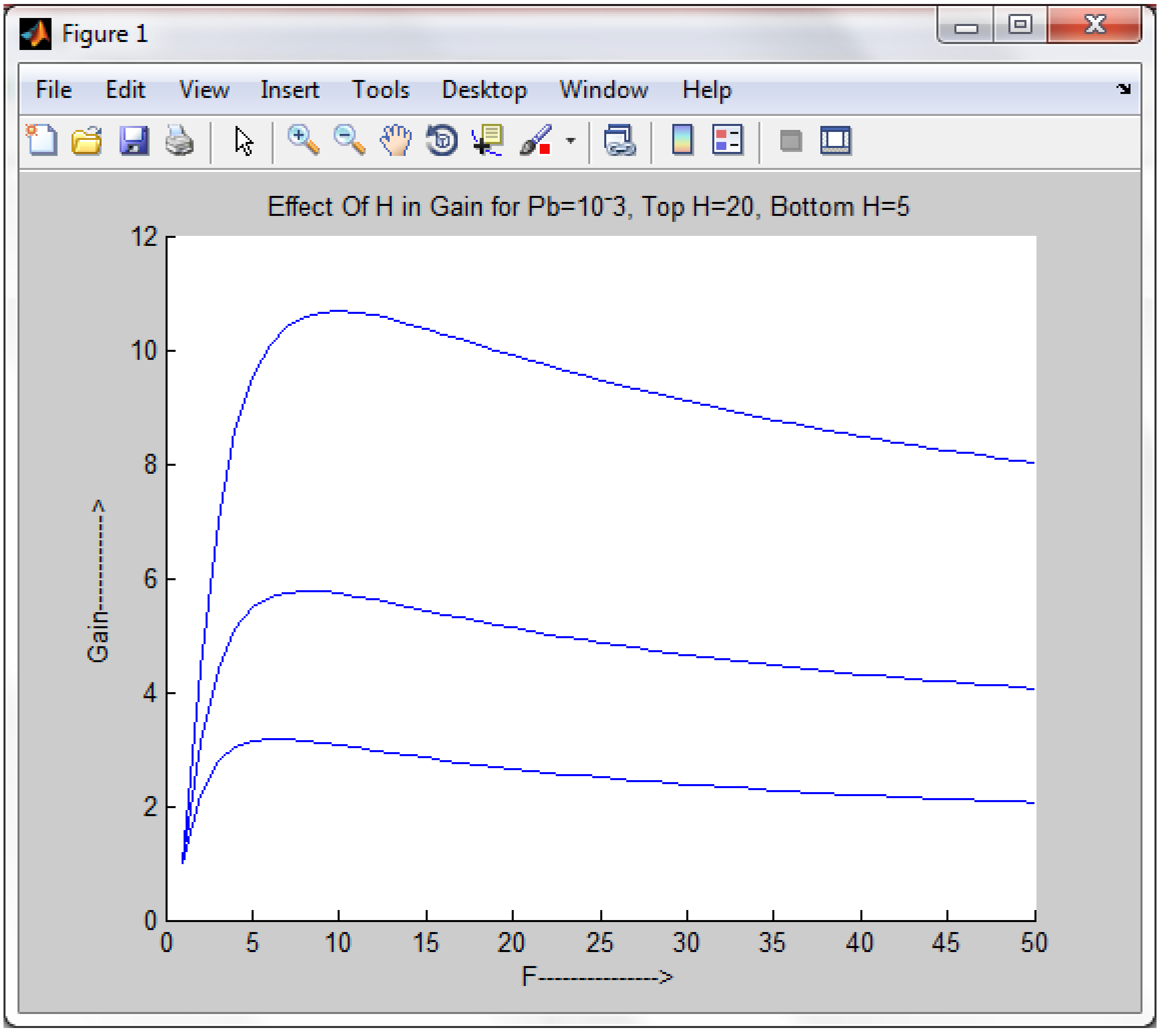


Figure 5.4 showing gain for Pb=0.001, H=5,10,20

5.4 Conclusion:

The following conclusion can be drawn from the plots.

1. Wavelength utilization increases with no of wavelengths for a given blocking probability, but the effect of H is small with wavelength converters.

2. But in second case, utilization increases but effect of path length is significant without wavelength converters.

3. Gain increases, then reaches maximum value and then decreases. But the gain comes at the cost of wavelength converter hardware.

In the previous section we have assumed blocking probability to be constant. But blocking probability variation with links is shown in figure 5.5 and comparison is done for first-fit and random algorithm. The following values have been taken for simulation.

No Of Channels C=11,

No Of Links =10,

Load (in Erlangs =5,10)

Figure 5.5 shows for load=5 and figure 5.6 shows for load=10.

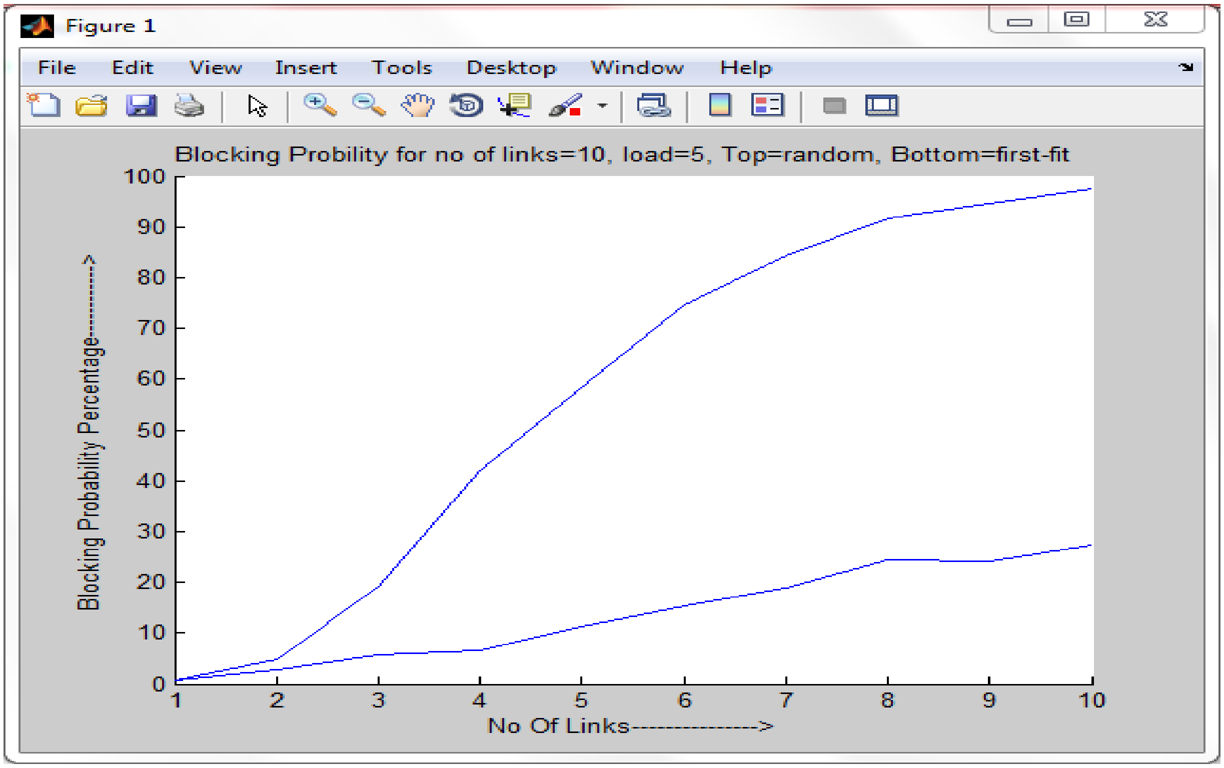


Figure 5.5 showing blocking probability for load=5 Erlangs

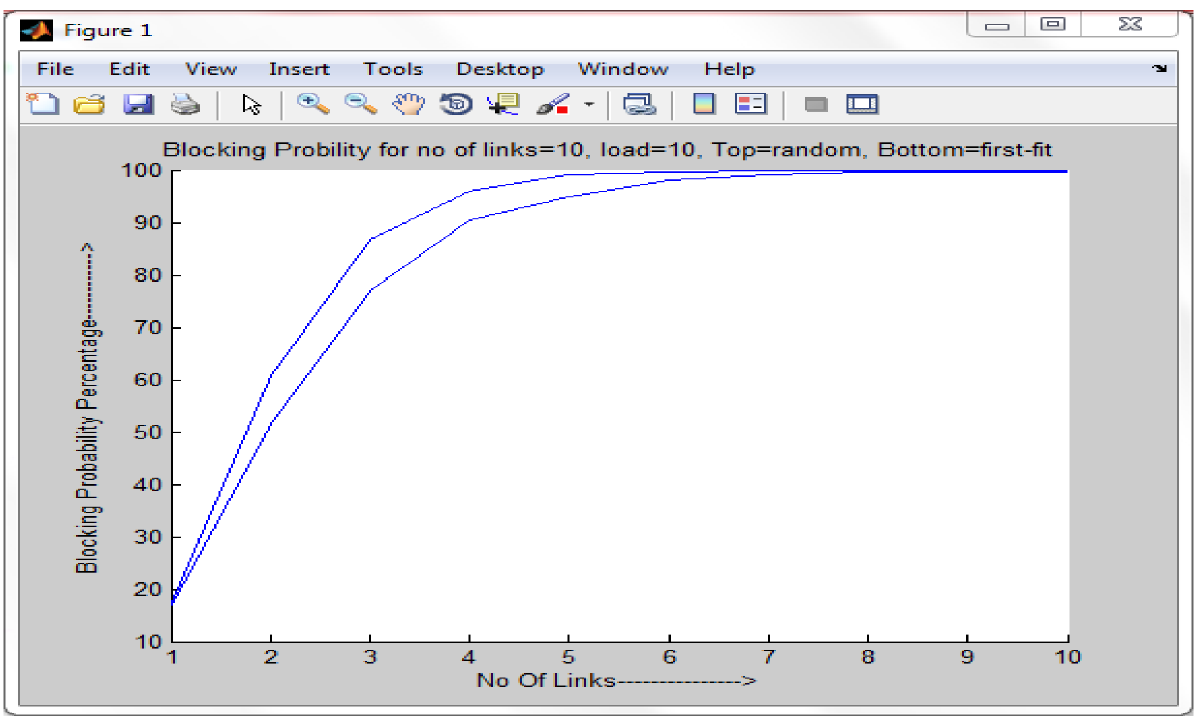


Figure 5.6 showing blocking probability for load =10 Erlangs

5.4 Conclusion for blocking probability calculation:

1. Blocking probability response for a network with 10 nodes is analysed with varying load.
2. Blocking probability increases with increase in load. First fit algorithm performs better than random algorithm with respect to blocking probability.

FUTURE WORKS

1. Instead of calculating one path from source to destination, several alternate paths may be calculated.

2. Advance analytical models may be employed for probabilistic analysis.

3. For architectural design PM-QPSK model may be considered for achieving high speed.

4. Advanced signal processing techniques may be employed for decision-circuit implementation.

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